Plans for the Ion Run in 2016

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Past Ion Runs at LHC

1000 ub-1 per experiment before LS2 PbPb

			Int lumi (ub-1)	Beta* (m)	Num. bunches	Ebeam (Z TeV)	Sqrt(s_nn) TeV
2010	PbPb	IP1/2/5	9.5	3	129	3.5	2.76
2011	PbPb	IP1/2/5	167.6/143/149.7	1	356	3.5	2.76
	pPb Feasibility		No collision*	11/10/11/10		3.5	
2012	Pilot pPb	IP1/2/5/8	1	11/10/11/10	12	4	5.02
2013	pPb	IP1/2/5/8/LHCf/TOTEM/ALFA	31940/31200/31690/2120	0.8/0.8/0.8/2	296/288/296/39	4	5.02
2015	PbPb	IP1/2/5/8	703.7/433/600/6.81	0.8/0.8/0.8/0.8/3	518	6.37	5.02

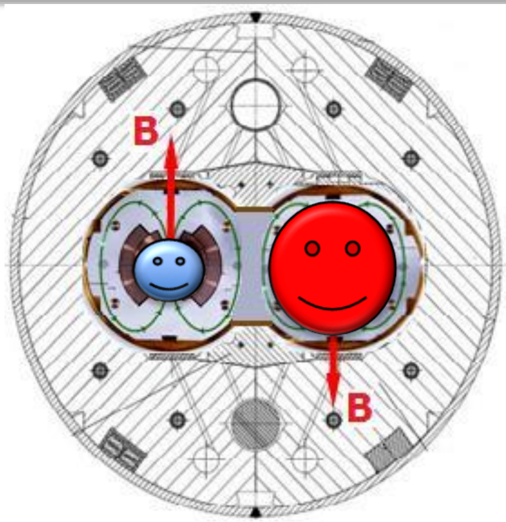
* PS injection septum leak

2016 experiment's requests

	2016		2018		
Option		$\sqrt{s_{nn}}\,(TeV)$		$\sqrt{s_{nn}}\,(TeV)$	
A	pPb	5.02	PbPb	5.02	ALICE, LHCb ATLAS,CMS
B	pPb	8.16	PbPb	5.02	ATLAS,CMS,LHCb,LHCf ALICE
C	PbPb	5.02	PbPb	5.02	ATLAS,CMS ALICE,LHCb

- ALICE ➔ minimum bias 1e28 cm-2s-1 (and some time at 1e29 cm-2s-1)
- LHCb 10xmore lumi than before ➔ 4-5 times more bunches

Particularities of pPb collisions @LHC



$$(B\rho)_p = (B\rho)_{Pb} = \frac{p_p}{e} = \frac{p_{Pb}}{Ze}$$

$$p_{Pb} = Zp_p$$

Equal beam rigidity fixes the momentum

Revolution period, ***T***, i.e. time needed for a particle to make a turn of length ***C*** ?

$$T = \frac{C}{v}$$

$$T_p = \frac{C}{c}\sqrt{1+\left(\frac{m_p c}{p_p}\right)^2} < T_{Pb} = \frac{C}{c}\sqrt{1+\left(\frac{A\, m_p c}{Z\, p_p}\right)^2}$$

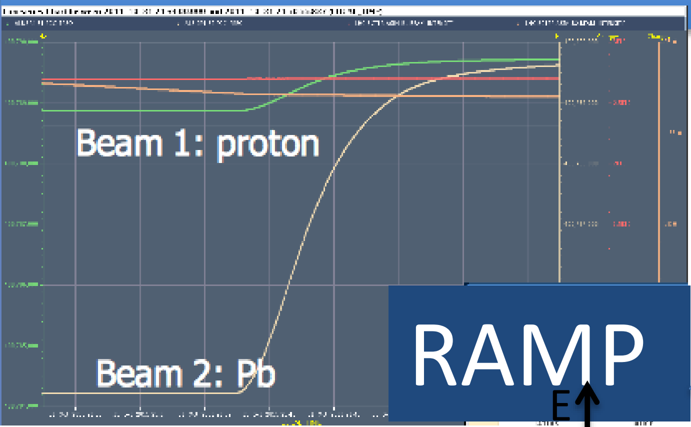
($A\, m_p \rightarrow m_{Pb}$; $Z\, p_p \rightarrow p_{Pb}$)

$$f_{RF} = hf_{rev} = h\frac{1}{T}$$

No more formulas!

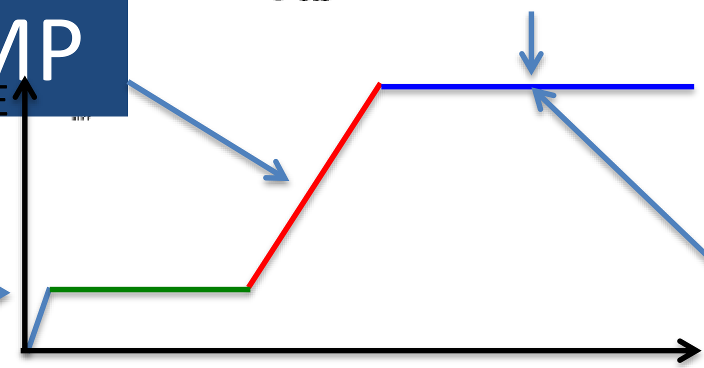
T: revolution period C: accelerator circumference c: speed of light
h: harmonic number

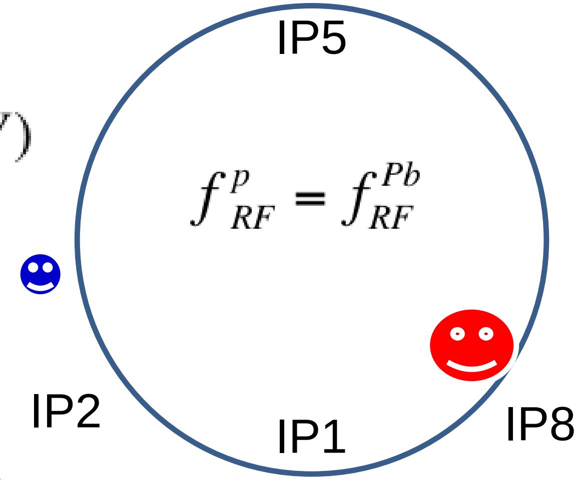
Particularities of pPb collisions

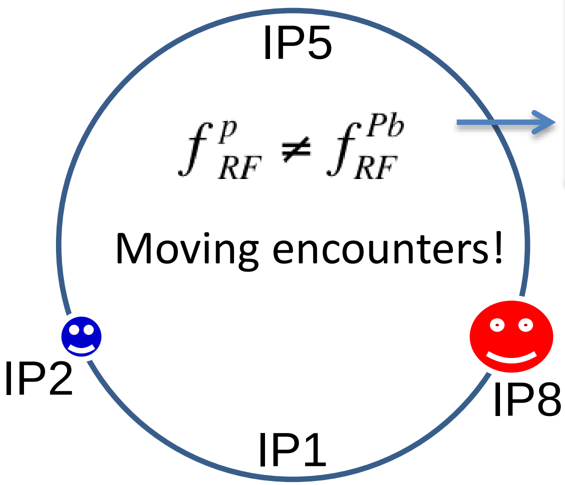


$$\Delta f_{RF} \cong 60Hz\ (4Z\ TeV)$$

$$\Delta f_{RF} \cong 22Hz\ (6.5Z\ TeV)$$

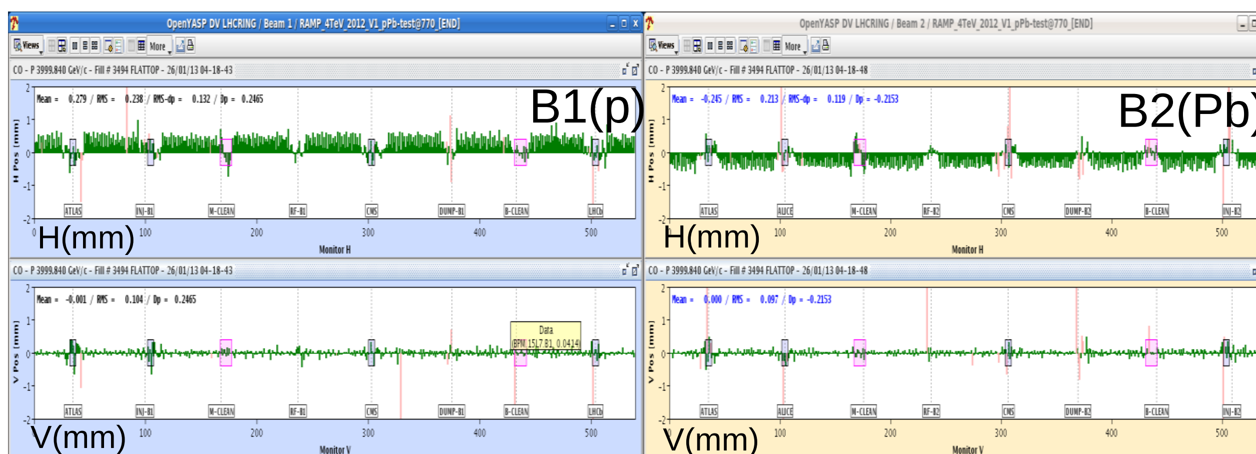






If @450 GeV TPb = Tp

$$\Delta f_{RF} \cong 5kHz \Leftrightarrow \Delta x \cong 70mm$$



Beam orbits at top energy with f_{RF} locked to B1

Particularities of pPb collisions: operation

- **RF**: unlocked frequencies during the ramp and cogging at flat top:
  - ✓ done already in 2013 routinely no issues expected there
  - ✓ if 6.5 TeV even better → reduced frequency difference between beams

- **BPM** operated at High sensitivity → orbit resolution is worst but still acceptable
  - Pb bunch intensity ~ 2.2e8 Pb82+ → ~1.8e10 p+ → pilot bunch
  - p+ bunch intensity ~ Pb bunch intensity

- **BPM interlocked:** big percentage of the 2013 fills were dumped because the lead beam dies faster → bunch intensity goes below the threshold and dumps the beam. For high sensitivity the threshold is 2.5-3.5 e9 p+ → we have to cope with

Particularities of pPb collisions: operation

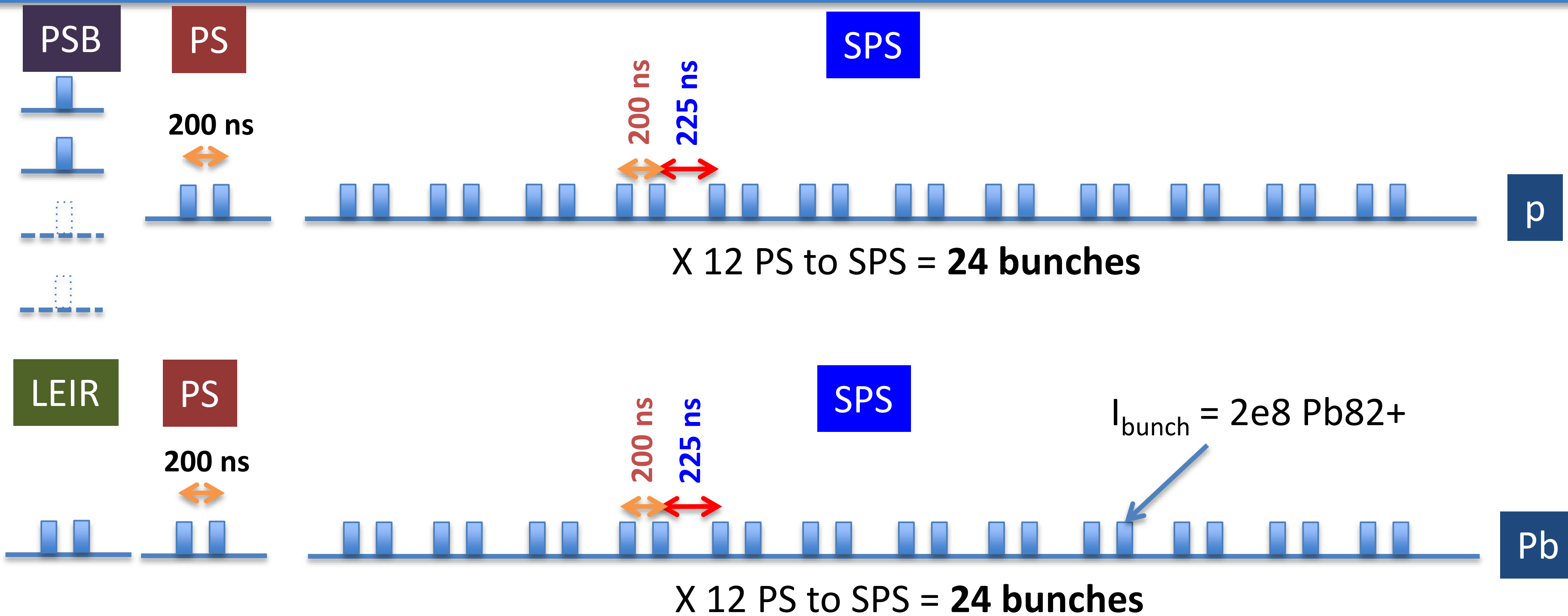
- **SIS/BIC**: new SIS/SPS BIC interlocks developed in 2013 ➔ same interlocks now
- **SIS:** new reference orbits needed for off-momentum operation

- **BLM thresholds**: needed to be increased in 2013 “learnt the hard way” after repetitive dumps during the ramp and squeeze ➔ in 2013 the collimator settings were set for 0.6 m beta* (tight collimator settings) but we end up running at 0.8 m ➔ if we optimise the settings for the selected optics we may not observe losses anymore

- **Luminosity losses compared to PbPb** in dispersion suppressors around experiments and in IR3 much reduced

- **Bound-free pair production** rate reduced to a few % of the PbPb rate

pPb injection patterns: achieved in 2013



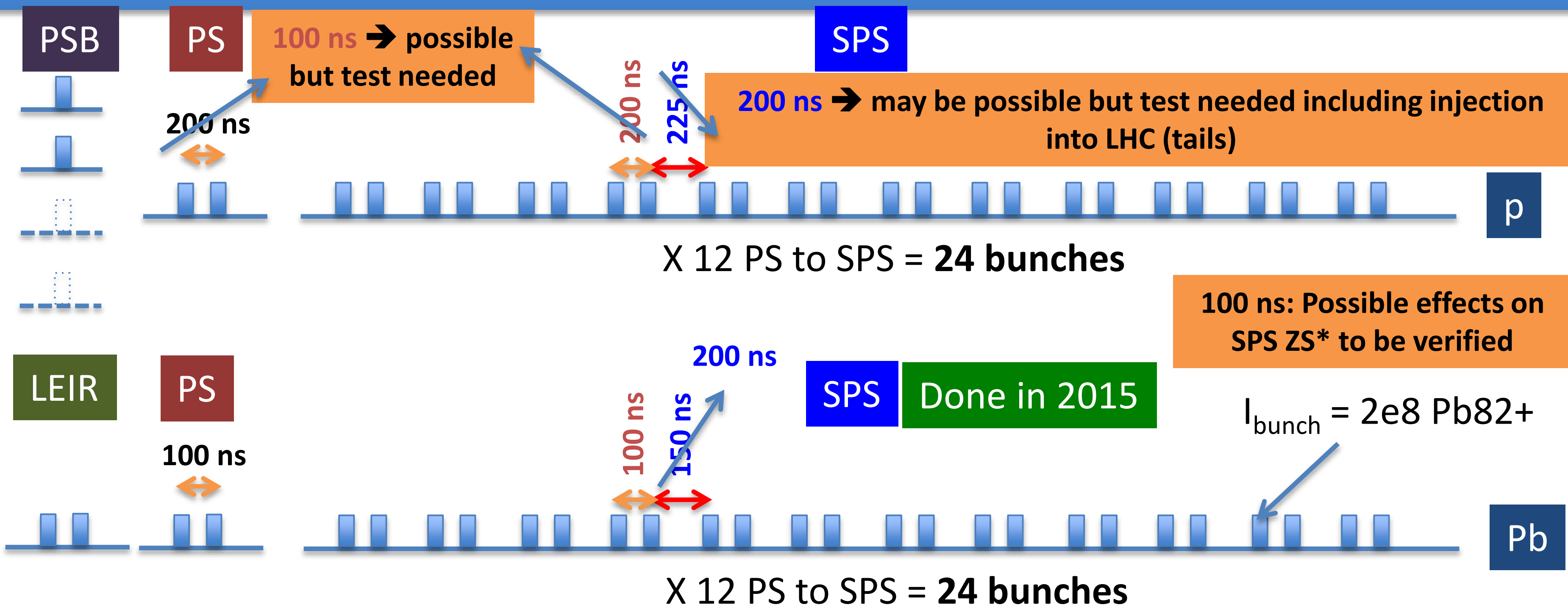
24 bunches x 12 into LHC

➔ Kb (IP1,2,5,8) = **296/288/296/39**

PS bunch compression

SPS injection kickers

pPb injection patterns: potential for 2016

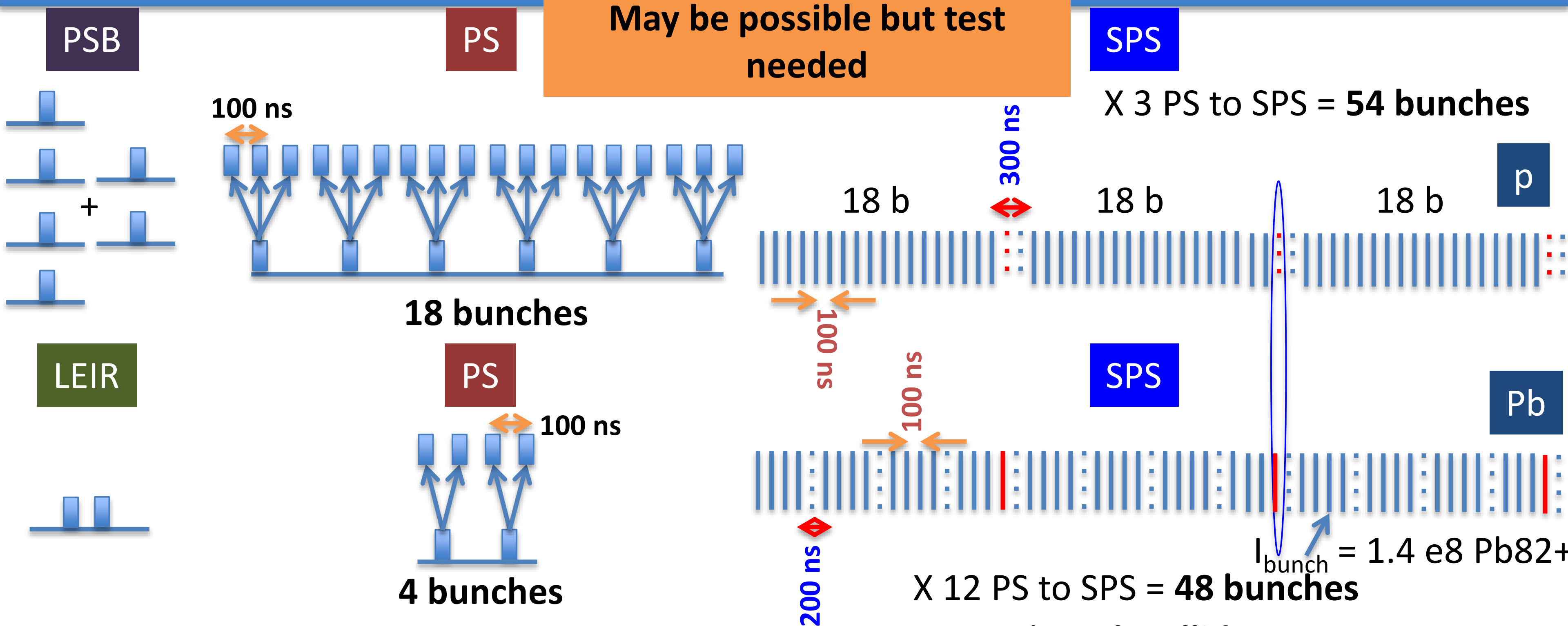


24 bunches x 12 into LHC

→ Kb ~ **400**

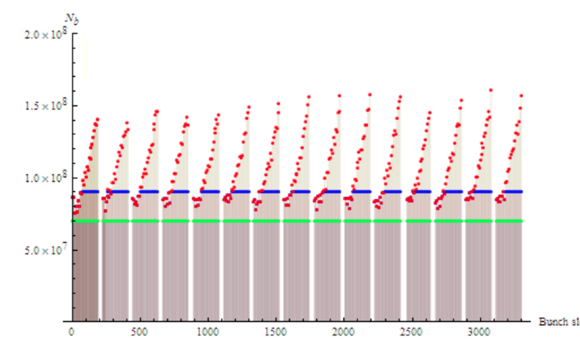
* SPS ZS: electrostatic septa for beam extraction to north area

pPb injection patterns: potential for 2016



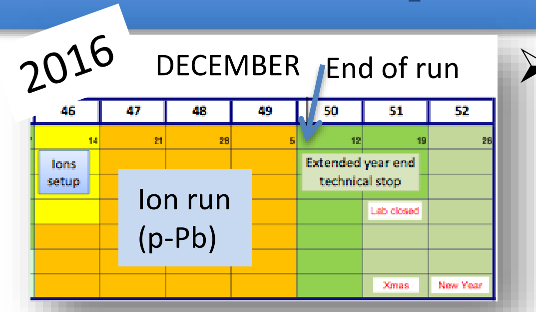
- **Faster Pb & p+ filling**
- **Less Pb bunch intensity; degrade less on the SPS flat bottom**
- **3 Pb bunches per SPS batch do not collide**

N.B.: 100 ns bunch separation needs beam-beam parasitic encounters studies. No problems observed in 2015 (PbPb) but beam-beam effects could be stronger in pPb.



PS bunch compression
SPS injection kickers

Optics in pPb: squeeze



- As the heavy-ion run physics time is always very short, operations capitalise on the well-established machine settings of the preceding pp run to commission as quickly as possible

- pPb run, however, always requires the commissioning of a new optics:

pp (IP1,2,5,8) ➔ $\beta^*_{min}/10/\beta^*_{min}/3$ ⇨ pPb, (IP1,2,5,8) ➔ $\beta^*_{min}/\beta^*_{min}/\beta^*_{min}/\beta^*_{min}$

which brings some extra difficulties as compared to pp:

➔ CHROMATIC EFFECTS DUE TO OFF-MOMENTUM OPERATION

- Due to the off-momentum orbits there is an intrinsic beta-beat which has to be calculated and superimposed to the usual beta-beat correction on-momentum

$$\frac{\Delta\beta}{\beta} = \frac{\beta_{off-p} - \beta_{on-p}}{\beta_{on-p}} = f(\beta^*) \Rightarrow 12\%$$

Beta-beat {
Modifies the focusing
More aperture needed
…

2013 (@ 4Z TeV) ➔ aperture issues downgraded IP2

β^*_{min} from 0.6 m to 0.8 m

First limitation to the IP2 β^*_{min} reach

- This limitation could be relax if E_{beam} = 6.5 Z TeV
  ➔ less off-momentum orbit displacement

Optics in pPb: squeeze

- Thanks to this correction the beta-beating is kept under control, tune shift remains within tolerances and dispersion-beating is very small for all steps of the squeezing procedure
- **except for one case (experience in 2013): beam 1 and negative momentum offset ➔ attributed to uncorrected coupling**

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Chromatic effects and their correction in off-momentum operation of the LHC for p-Pb collisions

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OPERATING THE LHC OFF-MOMENTUM FOR p-Pb COLLISIONS

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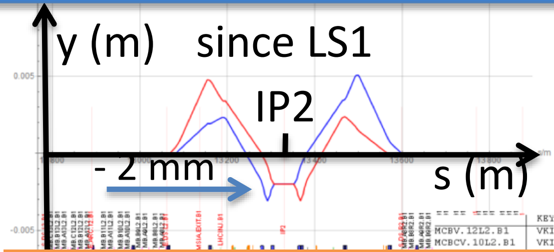
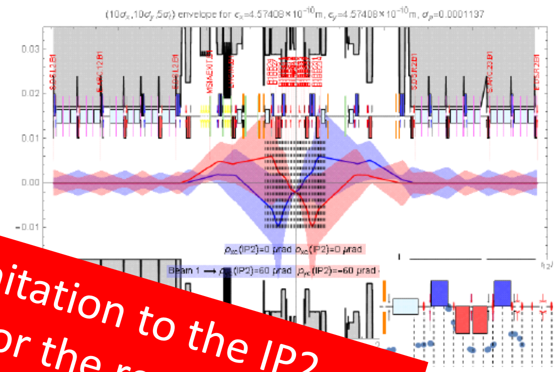
IPAC2013

Beta* limitations for ALICE in pPb



- ALICE detector vertical displacement of ~ 5 mm ➔ compensated in the optics by y = -2 mm IP displacement
- Needed in 2016 and beyond



- In 2015 @6.37 Z TeV and beta* = 0.8 m ➔ close to an aperture limit for + 60 urad polarity*

- 4 Z TeV ➔ bigger beam size ➔less aperture ➔ $\beta^*_{min} > 0.8$ m

Second limitation to the IP2 β^*_{min} reach for the rest of RUN2. Important to fix it in LS2

- **For min bias at 1e28 $cm^{-2}s^{-1}$ not a problem**
- **However the lower the beta* the longer ALICE can be levelled ➔ longer fills**
- **If IP1&5 at 0.4 m in pp 13 TeV run ➔ same optics is possible for pPb ➔ L peak higher**
- **Higher luminosity peak in IP1&5 ➔ faster burn-off ➔ less luminosity for ALICE**

Luminosity sharing is going to be a difficult subject

*(ALICE dipole – external = total)$_{half-angle}$

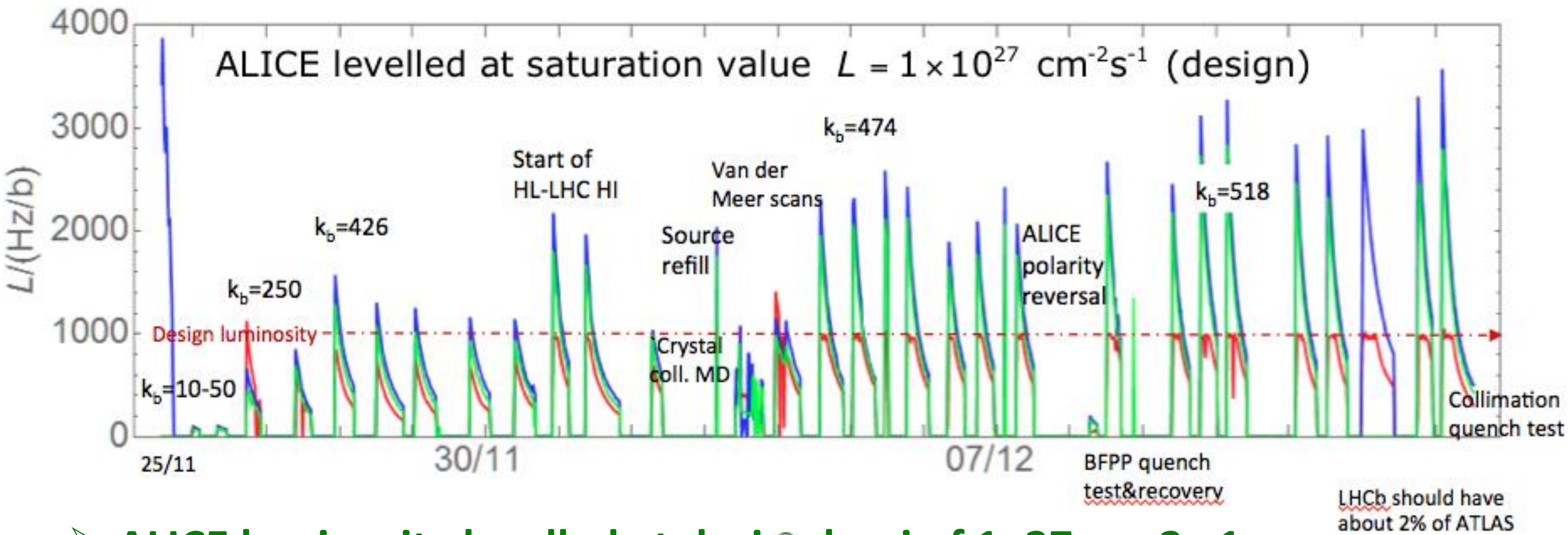
$$137\ \mu rad - 77\ \mu rad = 60\ \mu rad$$

2015 PbPb Highlights

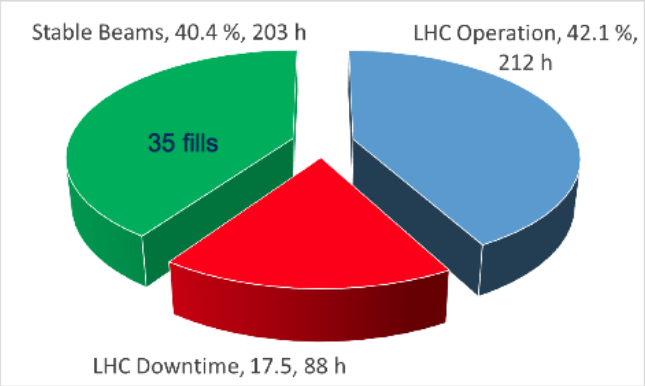
- **Linac3 and heavy ion source**: several improvements performed; after stripper foil exchange increased extracted intensity
- **LEIR:** intensive and extensive beam studies performed within the context of the LEIR crash program allowed an important transmission improvement
- **PS batch compression from 200 ns to 100 ns** → room for more bunches
- **SPS hard work** to reduce the losses during the energy ramp
- **SPS injection kicker switch replacement** → faster rise time with less jitter → batch spacing from 225 ns → 175 ns → 150 ns → **close to 500 bunches per beam in LHC**
- **SPS/LHC Transverse damper** team following up very closely the progress as to fully guarantee the required bunch stability

→ **Bunch intensities, average per bunch, 2e8 Pb82+**

2015 PbPb Highlights



- ALICE luminosity levelled at design lumi of 1e27 cm-2s-1
- ATLAS & CMS got peaks of over 3e27 cm-2s-1
- LHCb joint the PbPb ion run for the first time



- 30 End Of Fill, 5 dumped due to faults
- Fraction of premature dumps: 5/35 = 14.3 %
- Average turnaround (per SB) = 204/35 = 5.8 h
- Average Fault time (per SB) = 88/35 = 2.5 h

Potential performance (for high luminosity)

Calculated with the following assumptions:

- Number of colliding bunches = 400
- Pb bunch intensity (highest average achieved in 2015) = 1.8e10 p
- p bunch intensity (conservative, MD to achieve 4-5e10) = 1.8e10
- Normalized emittance (Pb,p) = 1.5 umrad, beta* = 0.8 m, IP1&5 ½ angle = 145 urad
- Run length (reference 2015 PbPb) = 21 days with 1.5 fill per day
- Average fill length = 6 hours (pPb 2013 dumped by interlocked BPMs, PbPb 2015 dumped by operator)

IP1&5	Ebeam (TeV)	Peak Lumi (cm-2s-1)	Integrated Fill Lumi (ub-1)	Integrated Run Lumi (nb-1)
PbPb	6.37Z	2.7e27	35	1
pPb	4Z	2e29	2600	77
pPb	6.5Z	3e29	3900	116

Within the usual 10-15% uncertainty

- **ALICE** → minimum bias 1e28 cm-2s-1 (and some time at 1e29 cm-2s-1). Studies needed to estimate how long levelling will last to calculate integrated luminosity
- **LHCb** 10xmore lumi than before → 4-5 times more bunches, not included in the calculations above. The bunch sharing needs detailed filling schemas preparation

Potential performance (for high luminosity)

IP1&5	Ebeam (TeV)	Peak Lumi (cm-2s-1)	Integrated Fill Lumi (ub-1)	Integrated Run Lumi (nb-1)
PbPb	6.37Z	2.7e27	35	1
pPb	4Z	2e29	2600	77
pPb	6.5Z	3e29	3900	116

Within the usual 10-15% uncertainty

How to increase the performance:

- If p bunch intensity = 4e10 ➔ pPb peak lumi increases by **factor 2**
- If beta*=0.4 m (not possible for 4Z TeV) ➔ peak lumi increases by **factor 1.5**
- Draw back: **higher Pb burn-off** ➔ shorten fill length:
  - Smaller impact in IP1&5 integrated lumi, may be a factor << 1.5
  - Less integrated lumi for ALICE (remember they are levelled to 1e28 cm-2s-1)
  - Greater p bunch intensity … beam-beam effects for Pb beam?
- Find filling patterns with **more bunches**; no penalization!

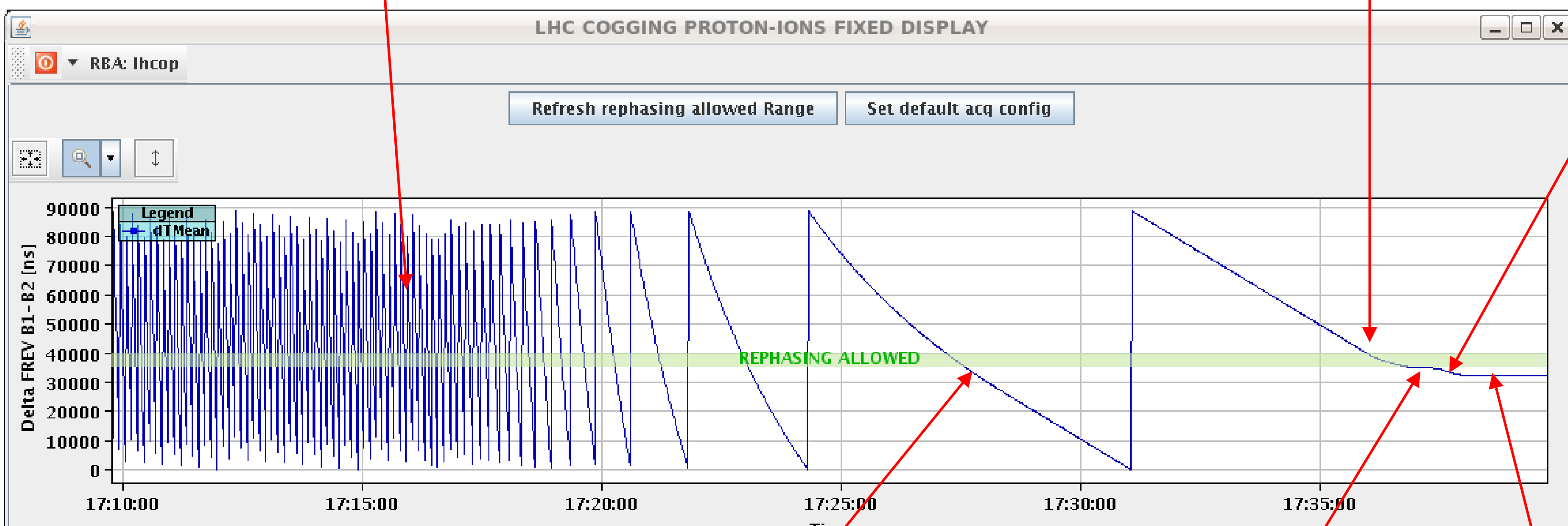
Backup

What's special about pPb: cogging

- We monitor the time interval between the revolution frequency markers (bucket 1 of both rings)
- Cogging takes 15 minutes maximum @ 4Z TeV
- It is fully automatic. The references were calibrated at the beginning of the run and not touched during the four weeks

Ramping

IP close to desired position, we move the beams to the common frequency



One last orbit bump to get IP exact

Start flat top but the IP is very far from the desired collision point. We move the beams onto the central orbits. With 60 Hz difference, IP makes one turn in 11 minutes

Same frequency but IP not exact

Done!

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